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Cell-Based Generalization of 3D Building Groups with Outlier Management

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ABSTRACT
In this paper, we present a technique that generalizes 3D building groups of virtual 3D city models according to a cell structure that is derived from infrastructure networks. In addition, the technique handles vegetation areas and outliers such as landmark buildings. Generalized 3D representations abstract from complex, detailed 3D city models and enable storage, analysis, exploration, and interaction at varying levels of scales. Our technique implements the cartographic generalization operators clustering, aggregation, and accentuation; it performs the generalization in four steps: 1) City model components are clustered based on the cell structure. 2) For each cell, the weighted average height is calculated, which is also used to automatically identify outliers. 3) Free space is subtracted from the cells such as in the case of outliers or vegetation areas. 4) The modified cells are extruded to building blocks; vegetation areas and outliers are modeled or, respectively, integrated separately. The paper demonstrates the application of the presented technique by a case study.

Categories and Subject Descriptors
I.3.3 [Computer Graphics]: Picture/Image Generation - display algorithms, viewing algorithms. I.3.6 [Computer Graphics]: Methodology and Techniques - interaction techniques. I.3.5 [Computer Graphics] Computational Geometry and Object Modeling.

General Terms
Management, Performance, Design, Human Factors.

Keywords
Generalization, 3D City Models, Clustering, Aggregation, Accentuation, Level-of-Detail, Outliers, Cells.

1. INTRODUCTION
Visualization of complex 3D city models is becoming an integral functionality of IT systems and applications that are based on spatial information. Currently, primarily photorealistic presentations of 3D city models are used and serve for multiple purposes such as in the fields of tourism, marketing, real estate, or Internet communication platforms.

With increasing model complexity, fundamental problems arise: the perception of a large-scale, high-detail 3D city model requires conscious attention of the user and perspective views produce information overload due to the finite resolution of the display media and the limitations of the human perception. In particular, areas that appear far away are visualized such that their components cannot be clearly seen anymore and, hence, their display is not anymore useful. While for photorealistic display, e.g., as background scenery in a movie or in a virtual sightseeing flight, the image complexity is appropriate [2][3], other use cases need an abstracted model [17].

Generalization in the scope of GI science [8] means the process of deriving abstract representations of spatial information subject to a given scale of the communication medium and the intended purpose and tasks to be supported. The process relies on, for example, selecting, combining, reducing, transforming, merging, and enhancing graphical representations; it can also "be understood as a process of representation of the real world by different models" [4], i.e., derivations of secondary models. In this context, our approach is concerned with generating multi-scale variants of virtual 3D city models. In particular, generalized 3D city models improve the perceptual quality of displayed spatial objects, provide better insights into structure and hierarchy underlying the city model, and facilitate 3D orientation and usability for large geovirtual 3D environments.

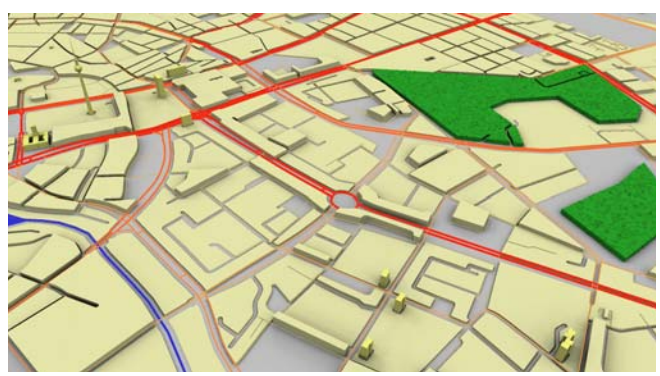

Fig. 1: Generalized 3D city model with integrated outliers, vegetation areas, road network, and water bodies.

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2. Related Work

Descriptions of elementary 2D map generalization approaches include [8][9][16][17]. First techniques for 3D building generalization using morphological operations are presented in [13][14]. Moving and merging near parallel faces to simplify 3D building models is suggested in [7], but is limited to orthogonal faces. An automated algorithm for generalizing 3D building geometry is described in [15]. Approaches that approximate the building geometry are either CSG based [19] or remodel the building model with a few planes optimized towards the original building [11].

Integrated solutions for multiple buildings generalization including building aggregation are rare: In [18], a framework for generalization of building models is presented. An aggregation using 2D projections of linear building groups is introduced in [1].

Real-time 3D rendering relies on efficient treatment of polygonal 3D data sets, and it provides a variety of LOD techniques, which can be classified into static and dynamic techniques in general. Static techniques provide discrete LOD representations (e.g., [12]), whereas dynamic techniques transform polygonal surfaces partially according to the current viewing situation (e.g., [10]). Commonly, all techniques simplify the original high-resolution 3D objects such that their appearance is preserved, but they are not generalized nor do the techniques consider specific semantics or characteristics of the type of the 3D object to be simplified.

3. Cell-Based Clustering

The first stage of our generalization technique (Fig. 1) decomposes the city area into clusters and groups city model components according to the cell in which they are contained. The clustering is based on the infrastructure network, e.g., streets, roads, and courses. The infrastructure network defines an implicit hierarchy as the weights associated with the network elements can be used to provide generalizations at different scales.

3.1 Input data

A subset of the components of a 3D city model is used as input data for the clustering stage: the building models and the infrastructure network. The infrastructure network consists of streets that can be divided into categories according to their relative weight or hierarchy level. These weights are mapped to a normalized weight w with $0 \le w \le 1$ (greater w means higher importance).

3.2 Clustering

To group building and site models according to the infrastructure network, in a first step the single polylines of the network are intersected to create polygonal cells. In a second step, the models are assigned to the cells in which they are contained.

In the first step, the hierarchy defined by the weights associated with the polylines can be used to create a cell structure depending on the desired *degree of generalization* (*DOG*). We introduce the term *DOG* in contrast to LOD, since LOD creation usually aims at reducing the computational workload while preserving the visual appearance. We intend a change of the visual appearance and aim at easier comprehension.

For a given *DOG*, all streets with a weight $w \ge DOG$ are taken to construct the cell network, which yields bigger cells for bigger *DOG*. For example, in a slight generalization, e.g. DOG=0.2 almost all streets are taken to derive the cell network, namely all streets with $w \ge 0.2$.

Using CGAL arrangements[1], the selected polylines are used to compute a cell structure.

In the second step, all building and site models that belong to a given cell are grouped. For this, aggregated point location queries are performed on the arrangement: For each building model, the center point of its ground plan is tested against the cells, and, if contained, assigned to the cell.

The result of the clustering stage consists in a set of polygonal cells, defined by the infrastructure network and having a group of contained building and site models.

4. Generalizing 3D Building Models

The second stage generalizes the 3D geometry of components contained in the cells. The resulting generalized block models do not occupy non-building areas, e.g., free spaces or vegetation areas, and street areas depending on the streets' weights.

To consider the space of surrounding streets and free spaces within the cells, the streets have to be buffered beforehand according to their weight to yield polygons. Using 2D Boolean set operations from CGAL, the streets polygons and the free spaces are then subtracted from the cell polygons.

To create aggregated 3D block models, a height has to be determined for each cell. To approximate and generalize the original building heights of a single cell, we calculate the weighted average height $\bar{h}$ for one cell based on the ground plan's area of each building (or site) model b :

$$\bar{h} = \frac{\sum_{i=1}^{n} height(b_i) \cdot area(b_i)}{\sum_{i=1}^{n} area(b_i)} \tag{1}$$

Alternatively, one could divide by the cell's area. However, in our tests, we preferred the calculation above because otherwise the resulting height tends to be perceived as to small. Still, in cells with a very low building density, no block should be created. Finally, the cells are extruded to the calculated height.

5. Outliers and Non-Building Areas

To ensure effective recognition of a cell with respect to its characteristic components, we have to identify outliers and to manage non-building areas in specialized ways.

5.1 Outlier Detection

We define city model components with a higher significance compared to their local neighborhood as *outliers*. In particular, outliers include landmark buildings (e.g., churches, towers, town halls, etc.) but have a broader definition since also monuments or site models such as bridges that stand out locally are outliers. Outliers can be identified by their component class and/or by attribute values, e.g., building usage [6].

In our current implementation, we follow a semi-automatic approach: On the one hand, outliers can be specified manually. On the other hand, outliers are detected in an automated way taking

[1] See http://www.cgal.org

into account their height. For it, we calculate the standard deviation σ of the height in a given cell. σ describes how models inside the cell deviate from the weighted average height. This way we can identify models considerably higher than the average, even considering the local height distribution. These models are said to be outliers if their height overtops the average a certain factor k relative to σ:

$$is\_outlier(b) = \begin{cases} true & height(b) > \bar{h} + k \cdot \sigma \\ false & else \end{cases} \qquad (2)$$

Depending on the targeted scale of the generalized city model and the desired number of outliers, the factor can be adapted. For large scales, $k = 2$ leads to reasonable results, while bigger values for k lead to a smaller selection.

5.2 Modeling Non-Building Areas

To integrate outliers and to represent non-building areas, their ground polygons have to be cut out of the cell polygons. This is done using Boolean set operations as done before for streets. Again, the polygons to be subtracted are buffered slightly to further expose them.

After resolving the ground space subdivision, we need to define 3D geometry for each cut-out area. In case of outliers, simply the unchanged original building or site models are placed in the cell. As the space for the building or site models has been cut out of the generalized block model, now the outliers are clearly visible. To create a homogeneous look, potentially existing textures of the outliers are stripped; they are just colored differently to accentuate them.

For vegetation areas, 3D geometry has to be created from scratch independently from their possible specification in terms of biotope components. Real-time 3D applications that rely on photorealistic visualization require detailed 3D vegetation models. For a generalized view, however, an abstract representation is needed that still allows the user to identify the type of area. In 2D, common signatures [8] have been established to distinguish, for example, broad-leafed trees and conifers.

In 3D, if buildings lie behind a wood, it has to be clear that they are invisible from the street, as otherwise the mapping visualization to reality is impeded.

Our technique starts with the 2D polygons that represents the vegetation areas and adds a certain degree of uncertainty to the contours as follows (Fig. 2):

For each segment

- Points are distributed evenly along the segment based on a given coarseness.
- Each inserted point is randomly translated within a circular area with radius =0.5*coarseness.

This is done for all contours (outer and inner loops) resulting in 2D polygons with slightly “shivered” outlines. To yield 3D geometry, they are extruded similar as the generalized block models to a specified height (defined by a default value or determined by the average height of vegetation objects).

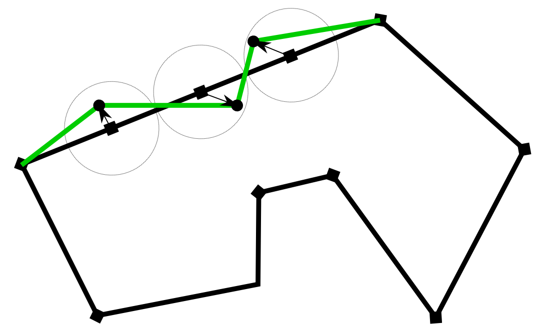

Fig. 2: The evenly inserted points are shifted randomly within a given radius to form a coarse line.

In contrast to the block models, the top surface is not plain but also created coarsely:

- Points are distributed evenly within the polygon based on a given coarseness forming a regular grid.
- Each point is randomly translated within a spherical volume with radius 0.5*coarseness.
- The points are triangulated using a constrained Delaunay triangulation with outlines set as constraints.
- Generated triangles outside of the outer loop are discarded. These are generated, as the Delaunay triangulation is convex, while the polygon not necessarily has to be convex.

Setting the color of, for example, a generalized 3D wood geometry to dark green completes the handling of vegetation areas (Fig. 3).

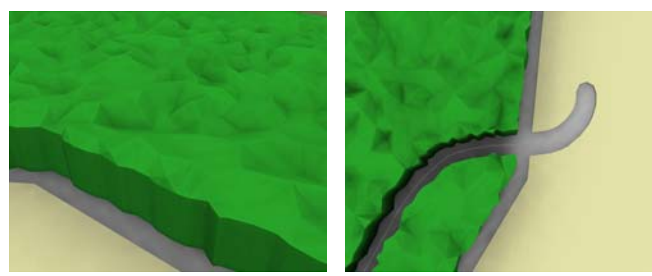

Fig. 3: Left: coarse wood surface. Right: Intersecting roads are cut out.

6. Navigational System Example

A navigation system based on 3D geoinformation, as illustrated in the introductory example, needs a generalized representation of a 3D city model to display a comprehensive visualization. The user of the system, e.g., the car driver, does not need photorealistic, high-detail building models, but a simple city model showing the way to the destination.

As a proof-of-concept, we have implemented a scenario for a navigational system (Fig. 4).

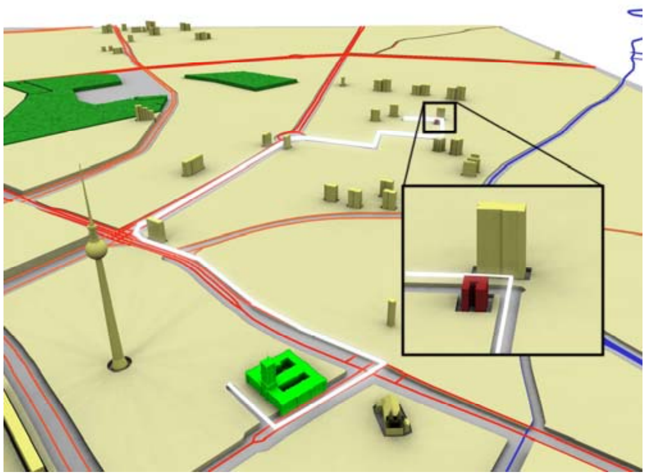

Fig. 4: Visualization of the route (white) between home (red) and town hall (green).

7. Conclusions

The presented technique generalizes virtual 3D city models containing building and site models, vegetation areas, and water bodies based on a hierarchical infrastructure network. Using the infrastructure network for the clustering proved to be appropriate to yield a comprehensible decomposition of the urban space.

Generalized virtual 3D city models can be used in many application areas. We have demonstrated our approach in a scenario for navigation systems.

In our future we will address low-density cells, which require finer resolution. Another clustering approach based on the proximity of building models within such cells would probably yield better results. The interactive visualization of the generalized 3D city model will also be investigated. One problem is how to deal with multiple representations of scale, possibly in one view, and how to transform between these representations, for example, while zooming.

8. Acknowledgements

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